ELECTROSTATIC DIGITAL MICROMIRROR USING INTERDIGITATED CANTILEVERS

Jin-Wan Jeon, Byeong-Il Kim, Ji-hyuk Kim, Hyung-kew Lee,
Jun-Bo Yoon, Euisik Yoon, and Koeng Su Lim

Dept. of Electrical Engineering and Computer Science
Korea Advanced Institute of Science and Technology (KAIST)
373-1 Kusong-dong, Yusong-gu, Taejon 305-701, Korea
E-mail: jwjeon@pretty.kaist.ac.kr

ABSTRACT

We have proposed an electrostatic digital micromirror utilizing interdigitated cantilevers. The electrostatically-actuated microstructure has been fabricated by the electroplated-nickel surface micromachining. Thanks to the unique design of the interdigitated cantilevers, the micromirror has an operational mechanism of a seesaw allowing accurate, reliable control of the final rotating angle. The fabricated digital micromirror has shown the rotating angle of ±9 degrees with an actuation voltage of 60 V.

INTRODUCTION

Recently, micromirrors have gained special interests in many micro-opto-electro-mechanical systems (MOEMS) applications such as projection displays, printers, and scanners. A DMD (Digital Micromirror Device) proposed and researched for a long time by Texas Instruments has demonstrated an excellent performance [1-2]. The DMD is a digitally-controlled micromirror array, whose primary function is to spatially modulate light. It is composed of arrays of movable micromirrors integrated on CMOS driving circuits. DMDs have been successfully applied to projection displays and laser printers and can be used for image processing and modulation. The hidden hinge structure has improved the area efficiency and the contrast ratio. The mirror has shown the binary tilting angle of ±10°. In addition, various deformable, torsional micromirrors have been reported as spatial light modulators with an analog operation. [3-5].

In this work, we have proposed a special unique structure of interdigitated cantilevers. Contrast to the previous DMD structure that utilizes a torsional motion of the hinge spring to rotate the overhang micromirror, only cantilevers are utilized to rotate the micromirror excluding any torsional actions. Due to this simple structure and the advanced fabrication method, we can achieve an accurate, reliable rotating angle and higher fill factors.

STRUCTURE DESIGN AND OPERATING PRINCIPLE

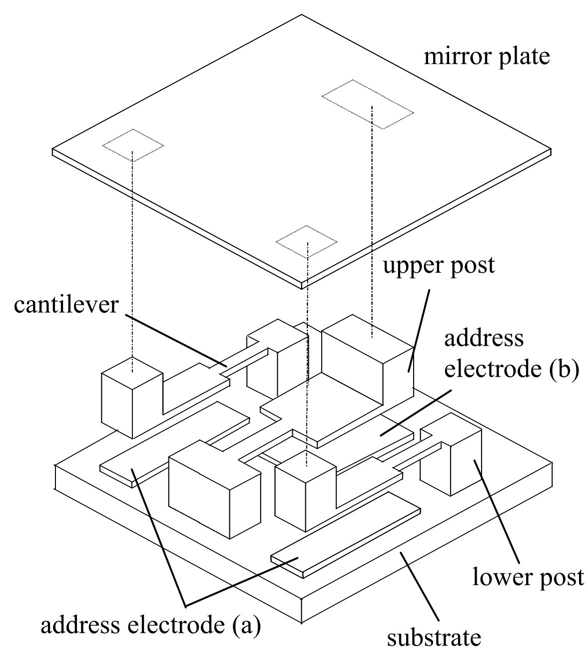

Figure 1: A schematic view of the proposed micromirror.

Figure 1 shows a schematic view of the proposed micromirror utilizing interdigitated cantilevers. The micromirror is composed of three layers: first, the bottom layer has metal electrodes which supply biases to the

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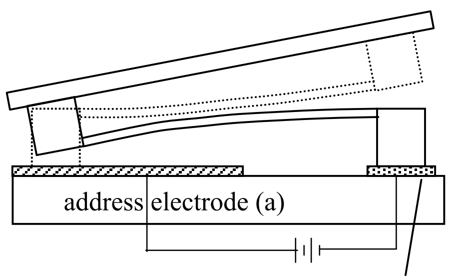
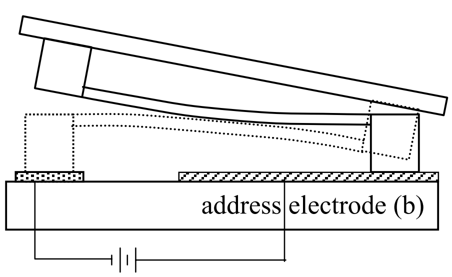
micromirror; in the intermediate layer, three interdigitated movable cantilevers are supported by the lower posts. Note that the cantilevers are placed in parallel but outreaching in the opposite directions with each other, so called interdigitatedly. This spatial allocation of cantilevers makes it possible to rotate the micromirror without any torsional springs; finally, the topmost flat micromirror is supported by the three upper posts which, in turn, are supported on each ends of the underlying cantilevers. The micromirror is actuated by the electrostatic pulling force biased between the bottom electrodes and the counter electrodes of the intermediate cantilevers. The interdigitated cantilever consists of a wide beam part designed for reinforcing electrostatic force and a narrow beam part for lowering down the spring constant, in hence, reducing the bias voltage.



(a) the rotating micromirror to the left side



(b) the rotating micromirror to the right side

Figure 2: A cross section of the rotating micromirror.

Figure 2 shows a cross-sectional view of the rotating micromirror. When the bias is applied to the surrounding two cantilevers and their corresponding bottom electrodes, the micromirror is bent down to the left side by their pulling forces as shown in Fig. 2(a). During this actuation, the center cantilever is forced to bend upward since its end is connected to the rigid micromirror by the upper post. When the bias is off, mirror easily returns to its original position by the restoring force in the three bent cantilevers. This can give us an advantage not to employ any complex structure for preventing stiction during operation in such a case of the present DMDs. When the bias is applied to the center cantilever and its corresponding bottom electrode, the micromirror is bent down to the right side as shown in Fig. 2(b). During this actuation, the surrounding cantilevers are forced to bend upward. The rotating angle increases as the bias voltage increases. Since the rotating motion is occurred not by torsional springs, but by well-characterized cantilever springs, more accurate and reliable rotation angle can be achieved.

Note that the area difference between the center and surrounding cantilevers are deliberately introduced to equal the pulling forces. Also, the micromirror is stopped to rotate when touched to the salient lower post of the same potential, so that there is no electrical shortage during the operation. When the device is used for binary operations as the DMDs, we can use the pre-defined tilting angle simply designed by a couple of dimensions of post heights and cantilever lengths.

FABRICATION

In order to fabricate multi-level metal microstructures, we have used a sacrificial metal mold (SMM) method which was previously reported in MEMS99 [6]. The structure is made of electroplated nickel, and electroplated copper is employed as a sacrificial layer in this work.

Figure 3 shows the cross sectional view of the fabrication process. On the silicon wafer, a dielectric material such as silicon oxide is passivated. As the seed metal, we have used thermally evaporated Ti and Au. Then the bottom electrode is formed by the conventional thick-photoresist lithography and nickel electroplating. Next, a photoresist mold for electroplating a sacrificial layer is patterned using the thick photoresist. The photoresist is UV-exposed prior to SMM electroplating to be dissolved away in the later process. Then copper shown in Figure 3(c) is electroplated as a SMM and mechanically polished to form the structure flat. The plating thickness of the copper decides the height of the lower post. Next, for making cantilever beams, upper posts, and a mirror plate, the process steps from Figure 3(d) through Figure 3(f) are performed. After all the process, only Cu mold is removed, as shown in Figure 3(g), by a selective chemical etchant. This technique can be easily adopted in the conventional CMOS process because of the low temperature process below 120ºC.

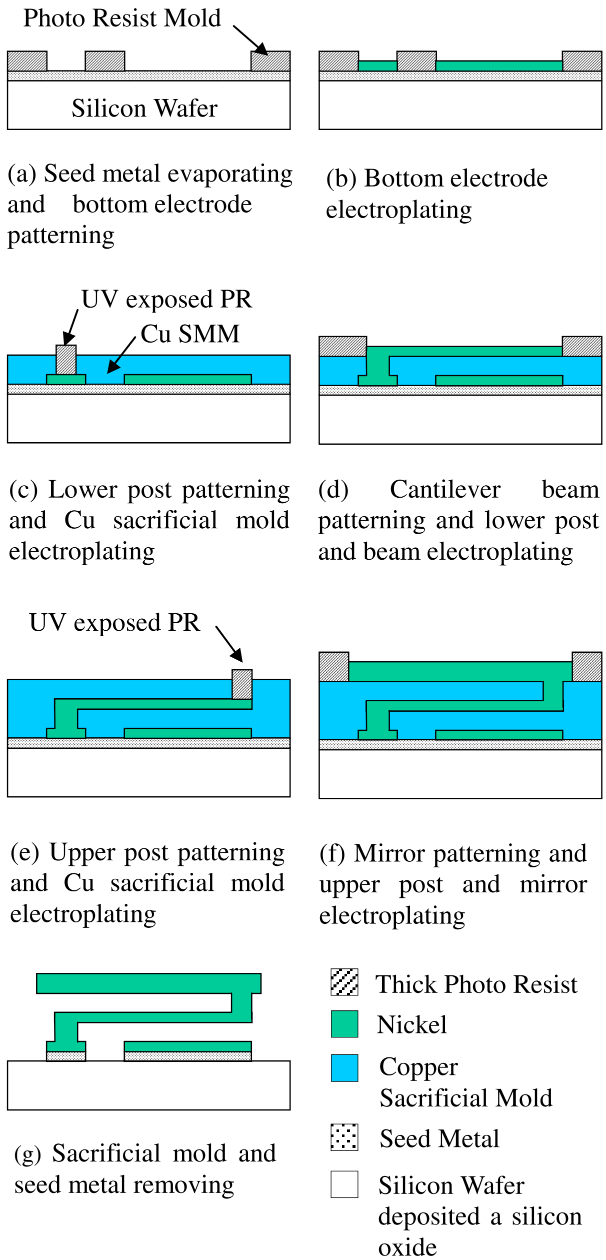


Figure 3: Fabrication Process.

EXPERIMENT AND SIMULATION RESULTS

A SEM image of a micromirror is illustrated in Figure 4. The mirror is supported by the completely-hidden interdigitated cantilevers. This makes it possible to achieve very high fill-factors (almost perfect). In order to apply the voltage biases, there are center and surrounding bottom electrodes and the single mirror address electrode which is electrically connected to the whole suspended cantilevers and the micromirror.

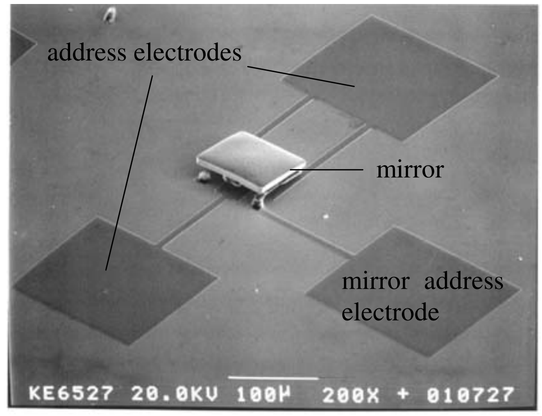


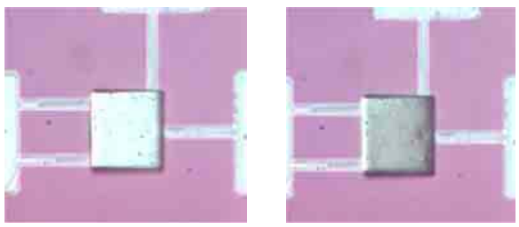
Figure 4: A SEM image of a micromirror.

The size of the micromirror shown in Figure 4 is 100 µm × 100 µm. The height of the lower posts is 10 µm and the upper is 8 µm. To ensure the same pulling force occurring in the two operational directions, we have designed that the width of one center address electrode is two times as large as that of other surrounding electrodes as described earlier. Also the width of the cantilevers is designed in the same way. Table I summarizes the approximate parameters of the fabricated micromirror.

Table I. Geometric parameters of the micromirror design. (The design values of the cantilever beams indicate the size of the wide and narrow beam parts, respectively.)

Geometries	*Design Value*
the size of the micromirror	100 µm × 100 µm
the height of the upper posts	8 µm
the height of the lower posts	10 µm
the thickness of the cantilever beams	1 µm
the size of the surrounding address electrodes	15 µm × 70 µm
the size of the center address electrode	30 µm × 70 µm
the size of the surrounding cantilever beams	15 µm × 45 µm 5 µm × 45 µm
the size of the center cantilever beam	30 µm × 45 µm 10 µm × 45 µm

Figure 5 shows the microscopic photographs of the operating micromirror. The micromirror has exhibited the operating micromirror. The micromirror has exhibited the tilting angle of 9° at the voltage bias of 60V as shown in Figure 5(b), which is larger than the expectation value of 4° obtained from the FEM simulation performed with the parameters listed in Table I. Figure 6 shows the FEM simulation result.



(a) No tilted mirror (b) A right tilted mirror

Figure 5: Microscopic photographs of the operating micromirror.

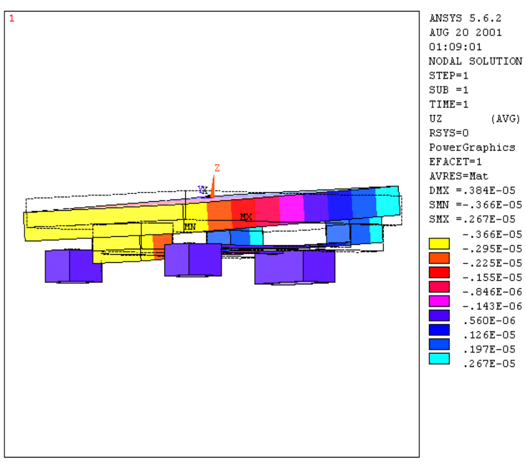


Figure 6: FEM simulation result by Ansys showing the deflection of the micromirror at the voltage bias of 60V.

CONCLUSIONS

We have proposed the new electrostatic digital micromirror. The micromirror is supported and rotated by the simple and unique interdigitated cantilevers which operates like a seesaw. It is fabricated by the metal surface micromachining method and has shown tilting angles of ±9° at the voltage bias of 60V. Further improvement of the performance of the micromirror can be achieved by optimizing the structure design and fabrication processes.

ACKNOWLEDGEMENTS

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